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Cause Mechanism study to Human Factors in Maritime Accidents: Towards a Complex System Brittleness Analysis approach

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Abstract

Human factor is becoming the primary cause of maritime accidents in recent years. The key to prevent accidents is to understand the accident causing mechanism of human error and the weakest link of human error system. Based on a large quantity of research of human errors in maritime accidents, by using complex system brittleness theory, a human error brittle model of complex system based on cellular automaton is built to analyze the internal brittle link of the system. By researching the influence degree of human error factors to the whole system, relevant accident control strategies could be proposed. The paper will provide a new method to research accident causing mechanism of human error.

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Keywords: Maritime safety; Human factors; Cause mechanism; Brittleness

1. INTRODUCTION

The present situation of research of maritime accident mechanism of human error forces on identifying the dominance factors, like crew's unsafe behavior leading to accidents. But the researches ignore the recessive factors, such as the prerequisite of unsafe behavior, unsafe supervision and organization problems. The human factors studies in field of Maritime safety management are still lacking. Therefore the reliability of control measures is low.

The brittleness of complex system can be defined as: under disturbances from internal or external of system, a subsystem of the complex system losses its normal functions and crashes, which influences other relevant

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subsystems and leads chain reactions of collapse. A maritime safety management system is a complex system which is composed and coupled by the subsystem of human, ships and equipment, environment. Since the brittleness of complex system is a born-in attribute, it will not disappear with the evolution of the system or the changes of external environment. Instead this attribute will become more and more serious with the evolution of the system. Human error factor is the key subsystem of maritime safe system, using brittleness theory of complex system to analyze accident-causing mechanism of human error to improve the maritime safety has important sense.

2. Maritime safe management brittle model based on cellular automaton

(1) Hybrid Cellular automata

Cellular automata (CA) is a kind of dynamic model, its space, time and state are discrete, time of the causal relationship and spatial interactions are localized to a grid structure. CA model consists of five components: cellular, state, neighbors, the cellular space, and conversion rules. Cellular is the basic unit in CA, which is distributed in the cellular space of each grid point. It is a kind of discrete space grid. The neighborhood is refers to all cellular aggregation which will be influenced by the changing value of the central cellular in the next moment. The conversion rule of CA is the mapping from a neighbor state to the central cellular next time state. In a brittle structure of complex system, a subsystem can be regarded as a cell of the CA model. All of its brittle associated subsystems are its neighbors. When the cell collapses because of disturbance, its neighbors will be affected. Followed a certain conversion rules, the brittle effects will spread around by effected subsystem in a self-replicating method. The brittle link degree determines the spreading range and degree. In the basic CA, the neighbor of radius is 1, cellular state is binary (0 and 1). The cellar of CA follows the same rules of evolution. Usually the rules of each cellular are not identical. It is called a hybrid CA, which is used in this paper. The mechanism of the CA is shown in figure 1.

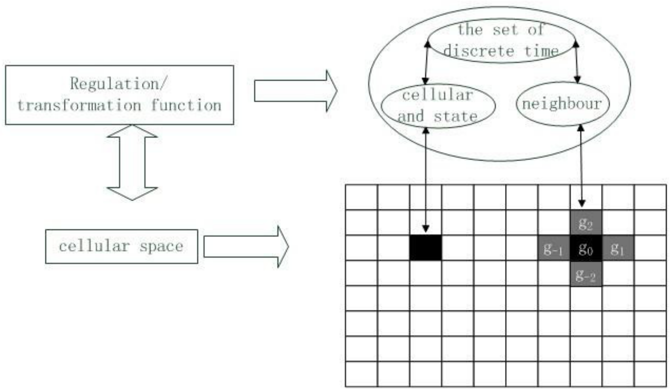

Figure1 Von. Neuman cellular automaton principle diagram

（2）Maritime safety management system's brittleness based on the entropy theory

One or several subsystem in maritime safety management system collapse caused by attacking, the impact of the external environment and internal factors, which will generate a chain reactions. If the chain reactions exceed the system regulation ability, it will make the entire maritime safety management system collapse. Then the brittleness of the maritime safety management system is fully motivated. The maritime safety management system crash characteristics called maritime safety management system's brittleness. The system's brittleness entropy value of every index is defined as follows **Error! Reference source not found.**:

A. Self entropy change of maritime safety management system

Self entropy change of maritime safety management system refers to the last entropy caused by maritime safety management system entropy change. It is sum of the previous entropy of the subsystem and the entropy increased of the internal system by the changing. The expression is:

$$S_i\left(t+1\right)=S_i\left(t\right)+G\left[S_i\left(t\right)\right] \tag{1}$$

In formula (1), $S_i\left(t\right)$ means the entropy of i subsystem in t moments;

Then the definition of Self entropy of maritime safety management system is:

Definition 1: maritime safety management system's entropy can be approximated as the system crash rate (relative entropy) of the exponential function, available formula is expressed as:

$$S_i\left(t+1\right)=S_i\left(t\right)\times（ke^{cp_i}+b） \tag{2}$$

In formula (2) :k、c、b are constant which are assigned according to different subsystems ; pi is the system of the relative entropy, refers to the ratio of current subsystem entropy to the subsystem critical entropy of collapse. The larger of the relative entropy, the closer is the subsystem in collapse status.

B. Brittle link entropy of maritime safety management subsystem

Brittle link entropy of Maritime safety management subsystem refers to the influence to the subsystem coming from other subsystem's entropy change. It is defined as SLX。

Definition 2: brittle link entropy of maritime safety management subsystem (SLX) is logarithmic function of every subsystem's relative entropy. It can be expressed as:

$$S_{LX}=w_{1a}H_{1a}+w_{1b}H_{1b}+w_{1c}H_{1c}+\cdots+w_{ia}H_{ia}+w_{ib}H_{ib}+w_{ic}H_{ic} \tag{3}$$

In formula (3), w_{ia}, w_{ib}, w_{ic} are brittle same, opposition and fluctuation weight coefficients, H_{ia}, H_{ib}, H_{ic} are brittle same, opposite and fluctuation entropy。$H_{ia}=-P_{ia}\ln P_{ia}$, $H_{ic}=-P_{ic}\ln P_{ic}$, $H_{ib}=-(1-P_{ia}-P_{ic})\ln(1-P_{ia}-P_{ic})$。$P_{ia}$ is the half value of the relative entropy of the subsystem i，the half of the ratio of entropy change value and critical entropy of the subsystem is P_{ic}

C. Negative entropy flow of maritime safety management System

Negative entropy flow of maritime safety management System S_n refers to

If subsystem has self-organizational ability and cooperativity, it can dissipate entropy flow coming from outside so that the subsystem can work normally. This entropy flow is negative entropy flow. The unit of it is bit.

D. Brittleness judgment to the maritime safety management system

If the whole system or several subsystems are disturbed, its entropy will increase. When it reaches the critical value, the subsystem will crash or lose its safe stability.

(3) Brittleness model of the maritime safety management system fragility modeling

The automata model is used to research the brittleness of the maritime safety management system fragility modeling. The status of every subsystem can be expressed via its entropy. The entropy changing is not only related with its own entropy, but also the negative entropy flow sources. it looks like a one dimension extended CA, and can be expressed as

$$S_i(t+1)=F(s_1(t),s_2(t),\cdots,s_i(t),\cdots s_n(t))-N_i(t) \tag{4}$$

Or it also can be expressed as:

$$S_i(t+1) = C_1 f_1(s_1(t)) + \cdots + C_i f_i(s_i(t)) + \cdots + C_n f_n(s_n(t)) - N_i(t) \tag{5}$$

Where Si(t) refers to the entropy of the subsystem i at moment t. Ni(t) refers to its neighbor area. C1,C2,…,Cn are correlation coefficients with value of 0 or 1. If it correlated with the subsystem i, then it is 1, otherwise it is 0.

From formula (5) shows the particularity of the one dimension extended CA of the system. Every subsystem might own same negative entropy source, but the gain different value from it. Furthermore, every subsystem has its own evolution rules.

The CA evolution rule of the system is:

- Initialize the current entropy value, critical entropy value and setting evolution times of the CA.
- Calculate the self-increasing of every sub-system.
- Calculate brittle link entropy of every sub-system.
- Calculate negative entropy that every sub-system gained.
- Calculate entropy change of every sub-system.
- Judge whether new sub-system is included or current sub-system is removed, if no, back to step B, otherwise go step G.
- set correlation coefficients to 0 for the sub-system removed, set correlation coefficients to 1 for the new sub-system included.

To simulate the system's safety brittleness by using CA, in order to get intuitive value, the relative entropy value of every sub-system is used and expressed as follow:

$$a_i^t = \frac{S_i^t}{S_{icr}} \tag{6}$$

Where S_i^t refers to the entropy of the sub-system i at moment t.

As the marine transportation safety system brittleness entropy and brittleness evaluation are closely linked, so its fragility modeling results can use cellular automata structure sequence representation as:

$$\begin{array}{cccccccc}
a_1^1 & a_2^1 & \ldots & a_n^1 & H_1^1 & H_2^1 & H_3^1 & H_4^1 \\
a_1^2 & a_2^2 & \ldots & a_n^2 & H_1^2 & H_2^2 & H_3^2 & H_4^2 \\
a_1^3 & a_2^3 & \ldots & a_n^3 & H_1^3 & H_2^3 & H_3^3 & H_4^3 \\
 & & & & \ldots\ldots & & & \\
a_1^k & a_2^k & \ldots & a_n^k & H_1^k & H_2^k & H_3^k & H_4^k
\end{array}$$

Where $H_1^j, H_2^j, H_3^j, H_4^j$ （j=1, 2, ..., k）represent the relative value of the brittleness probability entropy, the brittleness integrative probability entropy, the brittleness risk entropy and the brittleness integrative risk entropy of the system at moment j.

The Maritime safety system's brittleness integrative probability entropy and brittleness integrative risk entropy can reflect the degree of the brittle motivation of the whole system, the less value they have, the safer the whole system is. When its value close to 1, it means the system almost collapsed.

3. Conclusion

This paper studies the cause mechanism of human factors based on brittleness of complex system theory and the entropy theory. By using cellular automata to achieve assessment of maritime safety management on human factors. And it's a new attempt. The modeling will be simple, comprehensive, intuitionistic and being real-time by using cellular automata. Meanwhile, it has some unsolved problems:

(1)It's a difficult aspect to determine the cellular neighbor properly in contributing the cellular automata because of the complicated interaction relationship between various factors in complicated system;

(2)How to quantify the initial entropy is a difficult point, and the initial state of each cell will have a great effect on simulation results;

(3)The changing in the amount of entropy due to cellular interactions still needs further study.

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